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FERTILIZING DECIDUOUS FRUIT TREES IN CALIFORNIA

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INTRODUCTION

To determine the responses of various deciduous fruit trees to fertilizers under typical conditions of soil and climate in California, the Division of Pomology inaugurated a series of field trials in 1926. Data secured by farm advisors coöperating with growers in various counties are also available and have been used to supplement the results obtained by the Experiment Station. This bulletin summarizes all this information for the industry.

A few general considerations that affect the use of fertilizers and experiments designed to evaluate their benefits should first be mentioned. The absorption of mineral elements necessary for nutrition takes place through the root surfaces close to the growing points of the roots. It is necessary, therefore, to bring any nutrient added to the soil into contact with these absorbing surfaces if the material is to be utilized by the tree. Root distribution through the soil mass depends on a number of factors such as kind of rootstock; depth, texture, and temperature of the soil; presence of impervious layers of clay or hardpan; water table and moisture distribution. As Veihmeyer and Hendrickson[(4)3] have shown, water moves very slowly in the soil except for its downward penetration shortly after a rain or an irrigation and except for its upward rise (limited to a few feet) from the surface of a water table. The roots must go to the moisture instead of the moisture's moving toward the roots. Where the temperature is very high near the soil surface, root growth of fruit trees in that layer is generally restricted. At Davis, for example, relatively few roots are found in the top foot of soil during the summer months. There is little chance for nutrients to be absorbed from this region even though it may be the richest soil layer, except through temporary feeder roots sent up from below in the cool, wet weather of late winter or early spring before cultivation.

[1] Received for publication March 26, 1937.

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[3] Superscript numbers in parenthesis refer to "Literature Cited" at the end of this bulletin.

The significance in the fertilizer program of this scarcity of roots in the surface soil, even where roots have not been destroyed by cultivation, becomes evident when one considers the fixation of fertilizers by the soil.

Most soils can fix—that is, remove from the soluble condition—certain substances commonly used for fertilizers. Potassium (potash) is so fixed. Even on light soils whose fixing power is less than that of heavy soils, large applications of potassium are necessary for penetration into the root zone. Phosphate, even when supplied in large quantities, may also be fixed by the soil. And, as will be discussed later, ammonia is fixed in the same way as potassium.[4]

These considerations point to the fact that unless the fertilizer penetrates the root zone there can be no absorption, and, therefore, no response. As will be shown later, rather heavy applications of some fertilizers under some conditions are fixed in the surface soil and are not absorbed by the tree. Failure to get response in other cases may be due simply to the tree having an adequate supply of the particular nutrient. A further increase in that nutrient does not cause any improvement in tree behavior.

Response to fertilizers may take various forms. It may appear as a correction of chlorosis, that is, turning yellowish leaves green, or the disappearance of other nutrient deficiency symptoms. There may be a marked increase in growth, longer nodes, and larger leaves. There may be an increase in yield, which is the primary object of fertilization. The quality of fruit may be affected, favorably or unfavorably. Such fruit characters as sugar content, flavor, color, firmness, texture, and drying ratio have been reported changed by fertilization.

Trees are variable; rootstock, local soil variation, accidents such as broken branches, inroads of disease, and insect attack make the growth and yield of trees of the same variety vary from tree to tree in the orchard. To allow for such normal variations experimenters customarily use numbers of trees sufficient to be a fair sample. They also split up any treatment into two or more plots as a check on soil differences in the orchard. Another standard practice, probably less important in most cases, is to separate treated plots from check plots by a guard row, which prevents the roots from the check trees from invading the soil of the treated row and absorbing the fertilizer. Despite these precautions some differences will result from natural variation among the trees and not from

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[4] These general considerations are discussed further in:

Hoagland, D. R. Fertilizer problems and analysis of soils in California. California Agr. Exp. Sta. Cir. 317:1–15. Revised 1934.

Hibbard, P. L. Commercial fertilizers and soil fertility in California. California Agr. Ext. Cir. 57:1–38. Reprinted 1933.

the treatment. The amount of such deviation can be estimated by statistical study of the figures for growth or yield. A difference examined mathematically in this way and sufficiently large is called statistically significant and is probably not the result of chance.

An example of apparent differences which are not significant is supplied by a trial begun in 1926 west of Bogue in Sutter County on Phillips Cling peaches which was designed to provide the comparisons between N, K, NK[5] and unfertilized checks. Although unavoidable circumstances forced abandonment of the trial before completion and too soon for valuable results to be obtained, the preliminary figures indicated a response to N in this test. The data are here summarized: the average yield in pounds per tree per year for the eight check plots was 232; for two K plots, 210; for three N plots, 252; and for three NK plots, 279. The plots consisted of eight trees each.

The average gain was about 20 pounds apiece per year for trees receiving N over their adjacent checks, but a loss was recorded for those receiving K over those not receiving it. The average of N plus NK plots is 265 pounds per tree per year; that of the check plus K plots 227, a difference of 38 pounds.

At their face value, these figures might indicate a gain for N, alone or with K; a depression of yield by K alone; and an increased yield for K with N. A more logical interpretation is that under these conditions a gain or loss of 10 per cent is normal variation and should be disregarded. Actually, among the 8 check plots, yields ranged from 187 to 264 pounds per tree, a difference of about 40 per cent. Although averaging scattered plots has made these extremes disappear, differences attributable to normal variability are still present. In more uniform orchards differences of only 10 per cent may sometimes be significant, whereas in others 20 per cent may be unimportant.

In the investigations reported in this bulletin, various methods of chemical analysis have been used as seemed appropriate. No one method is universally suitable. An increased amount of a fertilizer found in plant parts such as blossoms, leaves, or fruit may serve, for example, to indicate that the tree has actually absorbed some of the material applied and has transferred it to the active aboveground parts. Soil analyses have been used primarily to follow the distribution or movement of materials through the soil rather than to diagnose the requirements of the tree.

[5] For the sake of brevity, symbols for the common fertilizers are here used as follows: N for nitrogen, P for phosphate, and K for potassium. Combinations of these materials are written NP for nitrogen and phosphate, etc. In mixed fertilizers the percentage composition is always given in the order NPK; for example a 4–6–10 mixture contains 4 per cent nitrogen, 6 per cent phosphate, and 10 per cent potash.

Such diagnosis does not seem practicable at present, as far as fruit trees are concerned.

FERTILIZER TRIALS

Peaches.—It is generally recognized that under the same conditions the peach tree responds to nitrogen sooner than any other fruit commonly grown. Light, sandy soils tend to be lower in total nitrogen than heavier ones, so that they are more likely to respond to nitrogen. Such soils are frequently low in other nutrients as well. The first group of these experiments, accordingly, was with peaches growing on light soils. One trial was on Tuscan (Tuskena) peaches on a Fresno sand near Modesto. This soil was low in potassium and nitrogen, and the experiment was designed to test response to those elements. In the last year of the experiment three plots also received phosphorus. The trees were eight years old when the trial began and were planted 24 feet apart. There is no hardpan in the first 6 feet, the depth to which soil samples were taken. Abundant irrigation water was available. The orchard was clean-cultivated throughout the summer, with a winter covercrop planted in the fall and turned under about the first of April.

Each plot consisted of 9 trees, and each treatment was in triplicate. Nitrogen was supplied to all treated plots each year. In 1926 and 1927 sodium nitrate was applied at the rate of 3 pounds per tree; in 1928 and 1929 ammonium sulfate at 5 pounds. In 1930 the treatment was changed slightly, three plots receiving ammonium sulfate at the rate of 5 pounds per tree, and three plots "ammoniated phosphate" at the rate of 7 pounds, the same amount of ammonia as in the other plots. The addition of phosphate in 1930 was made in order to obtain information on the effect of these combinations on split-pit, said, at that time, to be reduced by phosphate plus nitrogen. With four years of production records any marked deviation in yield due to the phosphate applied the last year was expected to be detectable. Potassium chloride was applied to each of three plots at the rate of 3 pounds per tree in 1926 and 1927, 5 pounds in 1928, and 10 pounds in 1929 and 1930. The yields obtained from these plots are given in table 1.

As these figures show, plots 1 and 2 produced more fruit than any other plots. Aside from plot 2 every check yielded somewhat less than either adjacent plot receiving nitrogen. The differences averaged about 50 pounds per tree and their consistency indicates a response to nitrogen amounting to about 20 per cent. This would be an increase of about 2 tons per acre. There is no evidence of response to potassium, at least in yield.

According to soil samples about 65 per cent of the K added was fixed in the surface foot, and none passed below the second foot. Analyses of

leaves and fruit showed an appreciable increase in the K content—about 20 per cent more than for the plots receiving N alone in the leaves and about 35 per cent more in the fruit. Despite this increase in K there was, as indicated above, no measurable response in yield.

Samples of the fruit submitted to competent judges were considered to be of the same quality irrespective of treatment.

These treatments had no effect on split-pit. Davis found that no other common method of fertilizing was effective, either.[6] Preliminary results

TABLE 1

AVERAGE YIELDS OF PEACHES IN POUNDS PER TREE ON SANDY SOIL FERTILIZED WITH NITROGEN AND POTASSIUM, STANISLAUS COUNTY

Plot No.	Treatment	1926	1927	1928	1929	1930	Average
1	N	366	264	451	436	416	386
2	Check	326	225	367	336	300	311
3	NK	230	239	346	313	235	273
4	Check	258	191	279	282	233	249
5*	N	281	220	326	364	275	293
6	Check	224	146	248	189	188	199
7*	NK	257	222	290	373	282	285
8	Check	236	172	274	252	211	229
9*	N	257	205	299	302	271	267
10	Check	238	150	236	224	229	215
11	NK	227	216	325	221	238	245

* Ammoniated phosphate was the source of N in 1930.

of a second trial, initiated at the same time in the same district on a heavier soil but discontinued before completion showed no response to either N or K.

Another experiment with Lovell peaches was begun in the Santa Clara Valley in 1929. This was designed to circumvent the difficulty of phosphate fixation in the surface soil. The fertilizer was applied in furrows deep enough to cut many small roots (which occur nearer the surface than at Davis), instead of being broadcast or drilled. The test was conducted by the Office of Horticultural Crops and Diseases of the United States Bureau of Plant Industry and the Division of Pomology coöperating with a Santa Clara Valley orchardist. Parallel experiments with Blenheim apricots and French (Agen) prunes will be discussed below.

The soil is very deep, nearly level, and well drained, with no marked change in texture to the depth of rooting. Though high in potash it is only moderately well supplied with phosphate.

During the experiment the rainfall was light, averaging only 10.2 inches annually, most of which fell between November and April. Irri-

[6] Unpublished data by L. D. Davis, 1934.

gation in the summer supplemented this supply, the square-basin system being used. The trees were allowed to wilt in the early fall each year.

The peach trees were planted 24 feet apart and were eighteen years old when the tests began. The customary pruning practices of the district were followed—namely, a severe pruning, the annual growth being thinned and headed to short stubs. Weak, injured, and crowded branches were removed. Walnuts had been interplanted in this orchard; and when, in 1932, the peach trees had to be cut back very heavily because of the increased size of the walnuts, the experiment was discontinued.

The treatments given were as follows: ammonium sulfate in furrows; treble superphosphate (46 per cent P_2O_5) in furrows and broadcast; ammonium sulfate and treble superphosphate in furrows; manure in furrows and broadcast; manure and treble superphosphate in furrows; and untreated checks. Six check plots were used. The applications were duplicated in the furrows but not in the broadcast treatments. Ammonium sulfate was applied at the rate of 5 pounds per tree the first two years and 3 pounds the last two. Phosphate applications were at the rate of 8 pounds per tree per year, and barnyard manure about ⅓ cubic yard. For furrow application the first three years two furrows were opened on each side of the trees with a plow to a depth of 5 or 6 inches. In the last year a disk plow and tractor opened a single furrow on each side of the tree to a depth of 8 inches. The materials were distributed along the bottoms of these furrows and covered.

Records were made of trunk circumference, yield, and general appearance of the trees. When the work was begun the average size of the trees was remarkably uniform. The fact that the trees of no plot differed significantly in average circumference from those of any other at any time during the experiment illustrates this point. The gain in circumference during the four years was also strikingly uniform.

The yields for the three years were also uniform, as shown in the following summary:

Treatment	Average annual yield in pounds per tree	Treatment	Average annual yield in pounds per tree
Check	269	Phosphate in furrows	289
Manure in furrows	264	Phosphate broadcast	273
Manure broadcast	233	Phosphate plus ammonium	287
Manure plus phosphate	253	Ammonium sulfate	266

No plot showed any increase due to treatment. The trees made longer shoot growth and had more abundant foliage in the plots receiving N.

An experiment that was designed to show the effect of fertilization on little-leaf of peaches was begun in 1929 by W. H. Chandler. The data

secured, as they relate to response of peaches to fertilizer, are presented in table 2. These trees were growing on deep, well-drained, light sand, and little-leaf was severe in 1928 and subsequently, except where zinc treatments were given. Applications of fertilizer were at the rate of 5

TABLE 2

AVERAGE YIELDS OF PHILLIPS CLING PEACHES FERTILIZED WITH NITROGEN, PHOSPHATE, AND POTASSIUM; MERCED COUNTY, 1931–1936 INCLUSIVE
(Pounds of fruit per tree per year)

Treatment	1931	1933	1934	1935	1936	Average
N	89	158	157	216	224	169
N	102	151	188	218	213	174
N*	142	181	227	232	245	205
NK	164	211	296	256	316	249
K	102	148	224	132	269	175
Check†	68	191	237	158	301	191
Check	67	160	195	120	258	160
Check	100	227	253	155	280	203
NPK‡	159	242	330	241	311	257
NPK‡	147	168	273	218	268	215
NPK	109	226	264	247	309	231
NPK	120	209	255	232	259	215
N	104	160	183	202	186	167
N	132	229	217	227	234	208
N	132	216	235	210	276	214
N*	88	200	237	160	269	191
NK	179	246	341	241	350	271
N	197	299	314	301	342	291
N	190	270	322	308	317	281
N	191	269	311	304	338	283
Check	136	226	240	297	327	245
Check	121	238	234	267	324	237
Check	157	251	240	311	349	262
N	222	299	263	304	357	289
NPK‡	228	289	337	356	390	320
NPK‡	174	283	313	323	340	287
NPK	163	242	282	333	324	269
NPK	154	175	247	282	277	227

* Not fertilized in 1936.
† Checks received N in 1936.
‡ No N in 1936.

pounds of $(NH_4)_2SO_4$ per tree in 1929–1934; 2½ pounds in 1935–36; 10 pounds of K_2SO_4; and 10 pounds superphosphate. The crop was not harvested in 1932.

The data show an average yield over the period studied of 216 pounds per tree for the checks, 225 for N plots, 175 for the single K plot, 260 for NK, and 242 for NPK. The fact that the averages for all treatments receiving N is above that of the checks suggests a slight response to that element. The variability is sufficiently great, however, so that any conclusions drawn as to the effect on yield must be tentative, especially in view of the somewhat uneven incidence of little-leaf over the block. These

data illustrate the point that even on very light soil, response to fertilization is not always certain or of great magnitude.

Another experiment with peaches, comparing various sources of N, will be discussed in a later section.

Prunes.— A series of plots was established in 1926 for French prunes west of Woodland on a silty clay loam to determine yield response and effect on sugar content and drying ratio of applications of N and K. The

TABLE 3

Average Yield of Prune Trees Fertilized with Nitrogen and Potash; Yolo County, 1926–1930 Inclusive

Treatment	Pounds fresh fruit per tree per year	Sugar content of flesh, per cent
Check	254	17.7
N	269	16.3
Check	259	17.5
NK	232	16.6
Check	234	17.6
N	235	17.0
Check	238	18.0
NK	201	17.4
Check	229	17.7
N*	174	16.3
Check	243	17.2
NK	230	16.9
Average of checks	243	17.6
Average of N plots	252	16.7
Average of NK plots	221	17.0

* This row was adjacent to a permanent levee and received less water than the remainder of the block; it was, therefore, excluded from the averages for N.

trees were planted 20 feet apart, were thirty years old at the beginning of the experiment, and had not been fertilized previously. The field capacity of the soil for moisture is about 30 per cent, approximately half of which is available to the plant. Those plots receiving nitrogen were given nitrate of soda at the rate of 3 pounds per tree in 1926 and 1927 and 5 pounds in 1928, 1929, and 1930. Potassium chloride was applied to the potash plots at the rate of 3 pounds per tree in 1926 and 1927, 5 pounds in 1928, and 10 pounds in 1929 and 1930.

As analyses showed, all or nearly all the K added was in the surface foot. The fact that the percentage of potash present in either leaves or fruits had not increased at the end of five years indicates no great penetration into the root zone.

Yields shown in table 3 have not been affected over the period considered either by potash or by nitrogen. Despite the long period of pro-

duction the trees produced heavy crops that were not increased by these fertilizers. The unfertilized trees, in fact, produced slightly higher yields.

The total sugar content of the prunes was determined each year except in 1930. A summary appears in table 3. The variability in sugar content between treated plots was slight. For any one year the range in percentage of fresh weight averaged less than 10 per cent of the mean. In 1926, for example, the average of the six treated plots was 17.2 per cent sugar. The maximum was 17.9 and the minimum 16.3, a range of 1.6 per cent. Since the trees apparently absorbed no potash, one would expect no response to the fertilizer. As Lilleland[1] has shown, however, the sugar content of prunes is independent of the potash supply in the tree whenever the amount applied to the soil has been sufficient to be readily demonstrated in the leaves.

The untreated plots averaged slightly higher in sugar than the treated, the difference, though small, being consistent and statistically significant except in 1926, the first year of the experiment.

An experiment on prunes was carried on in the Santa Clara Valley concurrently with that on peaches described above on page 7, but continuing through 1932. The materials used and the arrangement of plots were the same as for that experiment, and the plots were laid out in the same orchard. The trees received little pruning, and the fruit was not thinned. The summary of yields given below shows that there was no response to any treatment.

Treatment	Average annual yield in pounds per tree	Treatment	Average annual yield in pounds per tree
Check	84	Phosphate	71
Manure in furrows	70	Phosphate broadcast	52
Manure broadcast	60	Phosphate plus ammonium sulfate	87
Manure plus phosphate	82	Ammonium sulfate	103

The variations in yield are all within the limits to be expected without fertilization. There was no noticeable increase in shoot growth, no change in leaf color such as occurred in the peaches, no significant difference in trunk circumference. The analysis of leaves will be considered below under the phosphate-nitrogen relation.

Pears.—In 1928 a block of Bartlett pears at Lakeport was selected for study. The trees were over twenty-five years old, planted 22 feet apart on gravelly clay soil. The soil is deep with a heavy subsoil; it was once lake bottom. The proportion of clay decreases toward the upper end of the gentle slope on which the orchard is situated. The trees were not ir-

rigated. The average annual rainfall, about 36 inches, falls mostly between October and May. Frosts in the spring are not uncommon, the crop having been destroyed in 1932 and somewhat reduced in 1928, 1931, and 1933.

The part of the orchard used consisted of 41 rows. The odd-numbered rows 1–41 were guard rows. Every fourth row (2–6–10–etc.), 10 in all, served as a check. Treatments were, in order, NPK, N, K, P, and PK

TABLE 4

YIELDS OF PEARS FERTILIZED WITH NITROGEN, PHOSPHATE, AND POTASH; LAKE COUNTY, 1928–1933 INCLUSIVE

(Pounds of fruit per tree)

Treatment	1928	1929	1930	1931	1933	Average
Check	174	130	210	157	96	153
NPK	185	200	300	198	180	213
Check	205	190	260	216	138	202
N	220	280	360	252	204	263
Check	223	260	275	163	155	215
K	165	170	240	173	110	172
Check	110	130	190	117	100	129
P	130	190	260	108	130	164
Check	160	250	300	175	172	211
PK	135	190	250	132	111	164
Check	125	160	170	112	91	132
NPK	160	180	270	146	130	177
Check	125	120	120	90	130	117
N	135	160	180	104	105	137
Check	105	110	100	107	110	106
K	85	90	100	80	77	86
Check	95	100	120	67	90	94
P	85	80	110	42	60	75
Check	75	80	80	36	58	66
PK	55	70	90	42	53	62

applied to rows 4–8–12–etc., all treatments duplicated. Each plot contained 10 trees. In the spring of 1928, several weeks before blossoming, fertilizer was applied to the respective plots at the rate of 5 pounds of $NaNO_3$, 5 pounds of KCl, and 10 pounds of treble superphosphate (about 46 per cent P_2O_5) per tree. All material was broadcast. These same amounts were applied in 1929, but thereafter the amounts were increased to 10 pounds of each material per tree per year. A total of 50 pounds each of $NaNO_3$ and KCl and 60 pounds of superphosphate was applied per tree over the six-year period. All applications were given in the latter part of the dormant season.

Blossom counts were made at full bloom; fruit counts in June, after the major drop had occurred. Yield records were obtained for each tree in August. Leaf samples for analysis were taken from shoots 1 to 2 feet

long, the basal leaf from 10 to 12 shoots per tree being selected in all cases. All samples were composites of all trees in the respective plots.

The percentage of fruit set varied from year to year, largely because of varying degrees of injury by spring frosts. Counts were made only on the first ten plots. In every year when records were taken, the trees receiving N averaged somewhat greater in percentage set. The average of

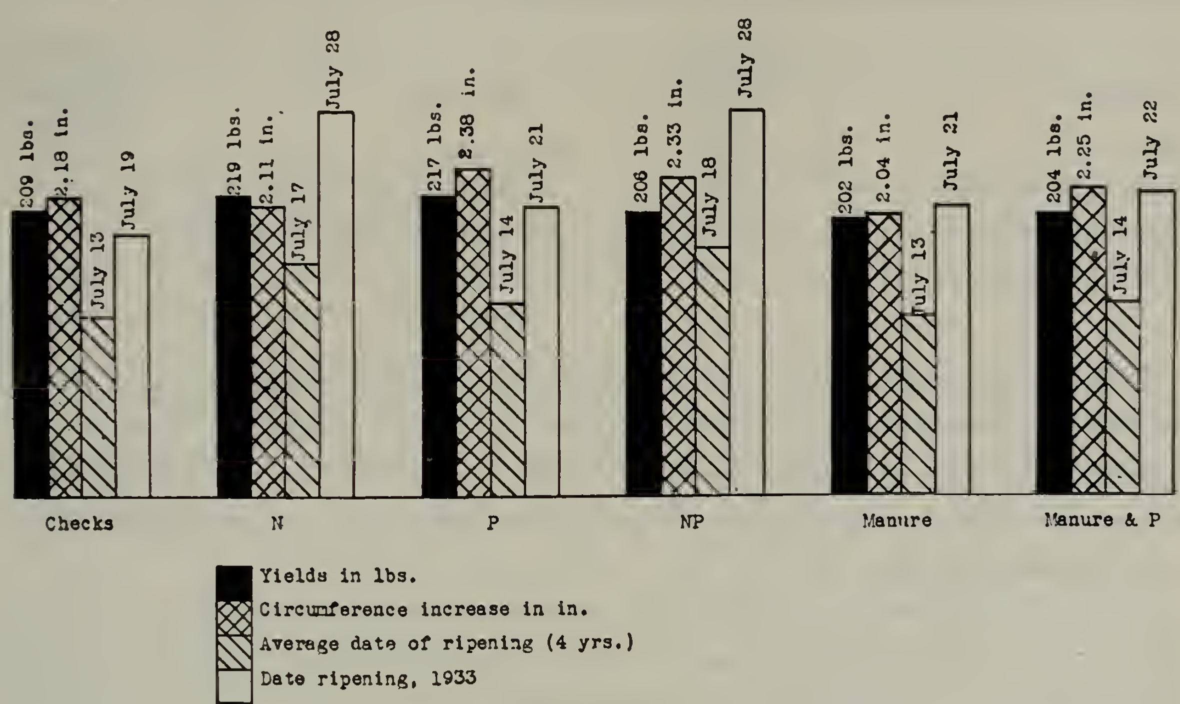

Fig. 1.—Summary of yield, circumference increase of trunk, and date of ripening for apricots.

the N and the NPK plots was compared with the average of the check between them and the two adjacent checks outside them. The figures for the plots receiving N were 12.4, 8.5, 11.7, 8.9, and 9.1 per cent set for the five years considered. The checks showed 9.8, 5.2, 8.9, 6.6, and 5.7 per cent set for the same years. There has been no consistent difference between the other treatments and the checks.

The yields of fruit have been higher on those plots receiving N than on the remaining plots (table 4). The average increase in total yield of each plot receiving N over the average of the two adjacent checks is as follows: NPK, 19.6 per cent; N, 26.2 per cent; NPK, 30.7 per cent; and N, 24.8 per cent. Of the remaining treated plots each averaged slightly less than the average of its two adjacent check plots, the differences not being significant in any case.

Apricots.—An experiment with apricots similar to the tests reported for peaches and prunes in the Santa Clara Valley was begun in the same orchard at the same time, 1929, and continued through 1933. The trees were handled like the peaches discussed above, and the treatments were

identical except that the broadcast phosphate was not duplicated. Besides the yield, trunk circumference, and appearance of the trees, the fruit size, date of ripening, per cent set, and drying ratio (one season) were noted.

The yields are shown in the tabulation below and are summarized graphically in figure 1, where is also shown the increase of trunk circumference and the average date of ripening.

Treatment	Average annual yield in pounds per tree
Check	209
Manure in furrows	202
Manure broadcast	201
Manure plus phosphate	204
Phosphate	217
Phosphate broadcast	218
Phosphate plus ammonium sulfate	206
Ammonium sulfate	219

As with peaches, there are no significant differences in yield or in growth as measured by circumference increase. There is, however, a significant delay in maturity of the fruit—more evident in 1933 than earlier. The dates of initial picking and final picking, not presented here, show the same delay.

Although there was no difference in size of fruit, the foliage was darker green and more abundant and the shoot growth more vigorous in the trees receiving N. The drying ratios, obtained for only one year, showed no significant differences.

Almonds.—Another part of this study is an experiment on nitrogen fertilization begun on almonds in 1930 in an orchard about 2 miles west of Arbuckle, California. This area in the western Sacramento Valley has an annual rainfall of about 15 inches, practically all falling between October and May. Most of the orchards are not irrigated and suffer from lack of water in the latter part of the growing season. The orchard used for these trials was not irrigated until 1934. The soil is a gravelly clay underlaid by a rather stiff clay. Water penetration is slow, and there is a considerable runoff of rainfall. At the start of the experiment the orchard was twelve years old. The varieties were Ne Plus Ultra interplanted with Texas 25 feet apart on the square system. Only Ne Plus Ultra was included in the experiment.

Because of deficient rainfall for several years, the trees were small for their age and were beginning to decline in vigor. Annual twig growth was less than ½ inch in length. Although a few fruit buds were formed in clusters on these short growths, the crop amounted to only about 2 pounds of hulled almonds per tree. Information on the effect of nitrogen under these conditions is very limited. The experiment was, therefore,

undertaken with some hesitation. It was feared that the nitrogen would induce increased growth in the spring while water was still available and that the resultant greater leaf areas would cause more rapid depletion of the limited water supply than had occurred in the past. The early depletion of water might prevent the crop from maturing, or even kill the tree. Ten plots of eleven trees each, separated from one another by guard rows, were selected; and half were given an initial application of 7 pounds of ammonium sulfate per tree. This amount was increased the following year to 10 pounds per tree, a rate maintained for the next four years.

Yield records summarized in table 5 were secured by harvesting and hulling each plot separately. The gross weight of unhulled nuts and the net weight of hulled nuts were recorded. The ratio of the weight of almonds before and after hulling was used to convert the weight of almonds not hulled by passage through the huller (the so-called sticktights) into terms of hulled nuts. A ratio between shelled and unshelled nuts was found and used for the small amount of shelled almonds cracked by the huller.

The fertilizer had practically no effect the first year except a slight improvement in leaf color. By harvest time a serious infestation of red spider caused nearly complete defoliation. The yield of the check plots averaged 2.57 pounds per tree compared with 2.55 pounds per tree for the N plots.

In 1931 the fertilized trees definitely improved in growth and yield. Despite the larger leaf area, leaf fall was later and the ravages of red spider were less in the fertilized than in the unfertilized plots. The average yield was greater than the preceding year, being 6.8 pounds per tree in the check and 7.9 in the treated plots. There was still overlapping in yield between treated and check plots. The check plots averaged 6.0, 7.2, 7.7, 6.5, and 6.8 pounds per tree; the N plots 7.2, 7.7, 9.0, 8.2, and 7.4. Although yields were low again in 1932, the treated plots produced more than the checks. The reduction in yield of the check plots compared with 1931 was about two-thirds; that in the treated plots only two-fifths. The trees appeared strikingly different, those treated having much more shoot length, larger leaf surface, larger and darker leaves, and less damage from red spider. Although the maturing of the almonds was delayed several days by the nitrogen, this delay had no practical importance.

Yields were higher in 1933 than in 1932. The check plots averaged 5.1 pounds per tree, and the fertilized plots 8.5, an increase of 65 per cent for these plots over the checks.

In 1934 a well was bored and irrigation water was made available to

supplement the rainfall. The effect of applying water in the growing season was immediately apparent. Growth of the whole orchard improved, and damage by red spider was reduced. The application of fertilizer was continued another two years to see whether the effect of the nitrogen would persist under the improved growing conditions. In 1934 the average yield of checks was 5.3, that of the N plots 8.7 pounds, per tree. Though the increase in yield per tree is negligible compared with 1933, the general condition of the trees was notably better. This fact was reflected in the yield in 1935, when the checks averaged 10.6 pounds per

TABLE 5

YIELD OF ALMONDS FERTILIZED WITH NITROGEN; COLUSA COUNTY, 1930–1935 INCLUSIVE

(Pounds of hulled nuts per tree)

Treatment	1930	1931	1932	1933	1934	1935
Check	2.9	6.0	2.4	5.5	4.5	9.2
N	2.2	7.2	5.3	6.7	8.2	14.2
Check	2.3	7.2	2.8	5.0	6.5	7.2
N	2.9	7.7	5.8	8.0	11.8	22.1
Check	2.9	7.7	2.3	5.0	6.2	10.8
N	2.4	9.0	4.1	9.5	7.2	28.3
Check	1.9	6.5	1.5	4.0	4.8	12.1
N	2.5	8.2	5.4	9.7	7.1	31.7
Check	2.7	6.8	2.4	6.2	4.6	13.5
N	2.6	7.4	2.9	8.5	9.2	24.2

tree, the N plots 24.1. The increases over the preceding season are nearly 100 per cent in the checks and 175 per cent in the treated trees. These yields are summarized in table 5. Yields per acre amount to over 700 pounds for the unfertilized trees and over 1,600 pounds for the fertilized. These figures may be compared with the state average of approximately 300 to 400 pounds per acre and yields of 1,500 to 2,000 pounds in more favored orchards.

Irrigation has brought the check plots from a four-year average of less than 300 pounds per acre to a two-year average of more than 400. It has increased the fertilized plots from a four-year average of less than 400 pounds per acre to nearly 1,200. The importance of water to successful almond growing under the experimental conditions is clearly shown. Nitrogen has a striking effect, whether considered on the basis of the period before irrigation or the period after irrigation was begun. Not only is the yield greater, but the quality is improved as compared with that of the unfertilized trees.

Nut size was greatly increased by the fertilization. Lilleland[7] obtained

[7] Unpublished data by O. Lilleland, 1932.

similar results near Chico: his fertilized Nonpareil almonds weighed 198 grams per 100 nuts; unfertilized, 156 grams per 100; shelled kernels, 131 and 93 grams per 100 nuts respectively.

In the years preceding irrigation the fluctuation of yield seemed to follow the rainfall of the preceding season more closely than that of the current season. The major depressing effect of moisture deficiency would then be ascribed to its effect on fruit-bud formation. The effect of irrigation was more noticeable the second year. Records from the nearest Weather Bureau station, in the same county, show rainfall of 9.68 inches in 1930–31; 13.39 in 1931–32; and 8.08 in 1932–33.

TABLE 6

EFFECT OF VARIOUS FERTILIZERS ON NITROGEN, PHOSPHORUS, AND POTASSIUM CONTENT OF PEAR LEAVES; LAKE COUNTY, JUNE, 1933
(Based on dry weight)

Treatment	N	P	K	P/N
	per cent	*per cent*	*per cent*	
Check	2.04	0.253	1.41	0.124
NPK	2.37	.205	1.09	.086
N	2.35	.202	0.97	.086
K	1.99	.283	1.68	.142
Check	2.04	.253	1.24	.124
P	1.98	.243	1.05	.123
PK	2.01	.211	1.08	.105
Check	2.11	.202	0.75	.096
NPK	2.29	.202	1.11	.088
N	2.19	.191	0.77	.087
K	2.02	.218	1.11	.108
Check	2.13	.211	0.76	.099
P	2.19	.204	0.93	.093
PK	1.89	0.191	0.83	0.101

LEAF ANALYSES AS AN AID IN INTERPRETING FIELD TRIALS WITH FERTILIZERS

Leaf samples collected from most of the trees on which data have been reported have been analyzed to determine whether the materials added have been absorbed and transported to the top. In some cases fruit and shoots have been analyzed as well. Normally leaf samples have consisted of the first full-sized leaf on shoots of average growth, 10 to 15 leaves per tree from each tree in a plot making up a sample. In preparation for analysis the leaves are washed to remove dust and spray residues, dried in an oven at 60° centigrade, and ground.

The leaf and fruit analyses of the first peach experiment have been mentioned. This is one of the very few cases where there was positive evidence of increased potash absorption by trees from surface applica-

tions of commercial quantities. The prune experiment begun at the same time produced no evidence of increased K absorption. For the pears an example of leaf-analysis-results is presented in table 6.

These analyses of pear leaves show that 60 pounds of superphosphate per tree may be fixed by the soil with no increased absorption by the tree, whereas 50 pounds of potassium chloride per tree causes only a doubtful increase of potassium absorbed on this soil type. Nitrogen, however, has

TABLE 7

EFFECT OF VARIOUS FERTILIZERS ON NITROGEN AND PHOSPHORUS CONTENT OF APRICOT, PRUNE, AND PEACH LEAVES; SANTA CLARA VALLEY
(Based on dry weight)

Treatment	Apricot			Prune			Peach		
	N	P	P/N	N	P	P/N	N	P	P/N
	per cent	*per cent*		*per cent*	*per cent*		*per cent*	*per cent*	
Nitrogen	3.39	0.352	0.104	2.61	0.237	0.091	2.40	0.146	0.061
Check	2.53	.461	.182	2.11	.328	.155	2.27	.189	.083
Nitrogen and phosphate	3.69	.339	.092	2.81	.244	0.087	2.65	.154	.058
Phosphate	2.71	.477	.176	2.11	.338	.160	2.37	.199	.084
Check	2.87	.415	.145	2.01	.328	.163	2.25	.191	.083
Manure and phosphate	2.97	.410	.138	2.13	.266	.125	2.23	.205	.092
Manure broadcast	2.64	.420	.159	2.11	.293	.139	....	....	....
Manure	2.68	.388	.145	2.19	.249	.114	2.05	.193	.094
Check	2.41	.438	.182	2.21	.277	.125	2.03	.183	.090
Check	2.64	.470	.178	2.17	.305	.141	....	....	....
Manure	2.92	.360	.123	2.25	.270	.120	2.41	.162	.067
Manure broadcast	2.67	.370	.139	....	....	....	....	....	....
Manure and phosphate	2.89	.339	.117	2.41	.286	.119	2.48	.175	.071
Check	2.62	.434	.166	2.17	.281	.130	2.27	.183	.081
Phosphate	2.77	.368	.133	2.27	.275	.121	2.19	.199	.091
Phosphate broadcast	2.75	.328	.119	2.31	.316	.137	....	....	....
Nitrogen and phosphate	3.83	.288	.075	2.46	.249	.101	2.45	.149	.061
Check	2.58	.374	.145	2.38	.271	.114	2.17	.160	.074
Nitrogen	3.37	0.270	0.080	2.65	0.213	0.080	2.57	0.142	0.055

been readily absorbed and can be shown in the leaves in all experiments where it has been used. Table 6 shows an interesting relation between phosphate and nitrogen contents of the leaves. Evidently the trees receiving N tend to have a higher N content and a lower P content than the others, giving them a lower P/N ratio. Another pear orchard, in the Santa Clara Valley, shows similar results. In the check plot, N is 2.53 per cent, P 0.229 per cent, and the P/N ratio 0.090; whereas in the nitrogen plot, N is 2.63 per cent, P 0.194 per cent, and the P/N ratio, 0.074.

Analyses of samples from the experiments in the Santa Clara Valley reported above for peaches, prunes, and apricots are given in table 7. The peach leaves were collected on June 2, 1932, and the apricot and prune leaves on May 25, 1933.

Despite the variability shown from plot to plot, the same sort of relation as for pears evidently exists.

Apricot trees near Winters, some of which had received calcium nitrate, were also sampled, with the following results: check trees, N 2.15 per cent, P 0.365 per cent, P/N ratio 0.177; N plot, N 2.57 per cent, P 0.277 per cent, P/N ratio 0.108. Other examples may be found in the literature.

Another aspect of the relation between P and N has been brought out by Lilleland,[1] who has shown that large amounts of P when injected into the soil to a depth of 4 feet around the roots of peach trees have decreased the absorption of N. The trees show N deficiency, the leaves being yellowish and the shoot growth shorter than in the checks.

As Lilleland has pointed out, the interpretation of plant analyses must depend on data regarding growth and fruiting as well as on actual analyses of plant parts; the K and P percentages in leaves particularly are depressed by heavy fruiting.

COMPARISON OF RESULTS OBTAINED BY USING NITROGEN FROM DIFFERENT SOURCES

Trials now in progress are designed to give more accurate information on the relative merits of the more important sources of nitrogen used in orchards. One such trial was begun in 1933 on mature Libbee peaches in Sutter County. The soil is a sandy loam, deep and well drained. Adequate irrigation water is available. Plots were laid out, each containing 10 trees in triplicate except the checks, of which there were 7. Sources of nitrogen were ammonium sulfate, calcium nitrate (nitrate of lime), urea, and calcium cyanamid. The initial amount of this latter material was small because the cyanamid is dangerous in large doses, so that the makers recommend light applications. Three pounds per tree of cyanamid was applied on February 1, 1933, in accordance with the precautions suggested by the makers. The other materials were applied in quantities to supply equal amounts of nitrogen. These applications were repeated on February 13, 1934. The cyanamid treatment was stopped after 1934. In 1935 the applications were increased to 4 pounds of ammonium sulfate per tree and its equivalent of urea and nitrate of lime. In 1936 they were further increased to the equivalent of 5 pounds of ammonium sulfate per tree. "Ammophos 16–20" was applied in 1936 to the plots formerly receiving cyanamid.

Samples of blossoms were taken at full bloom on March 23 and of leaves at intervals subsequently, to determine whether there was any difference in the time at which the different materials made themselves

evident in those parts. No difference was found in the nitrogen content of blossoms. There was no difference in the time at which the percentage of nitrogen in the leaves was found to be greater in the treated plots than in the checks. On April 13, the percentage in all treated plots was higher than in the checks. The February rainfall—about 0.65 inch—was insufficient to carry any into the root zone; and before the March rains—about 2 inches—there had apparently been enough nitrification so that availability was not greatly different in the various treatments. The leaves from all fertilized plots showed substantially the same nitrogen content.

Thus far ammonium sulphate and calcium nitrate have increased yields, the trees that received these materials averaging about 20 per cent greater in yield than the checks. No such gain has been recorded for urea or cyanamid under these conditions. After gains for the first two years the urea plots show losses the next two, and the average for the four years is not significantly above that of the checks. The plots receiving cyanamid showed some leaf burn in 1933 and more in 1934, accompanied by a drop in relative yield in 1934. The grower coöperating in this trial requested that this material be discontinued. After skipping one year, 1935, these plots were given Ammophos; but the trees did not respond in 1936.

There is apparently no ready explanation for the decreased yield of the peach plots receiving urea. This material has been used successfully elsewhere and in moderate amounts is not toxic. The trees do not appear to be less flourishing than their neighbors.

Trials of cyanamid on peaches and plums at Davis have given somewhat contradictory results. Peaches showed severe damage, irrespective of the amount used above 2½ pounds per tree; but the injury caused by 2½ pounds was slight. Applications of 7½ and 10 pounds killed the trees. Japanese and European plums given applications of 2 pounds per tree showed no leaf-burn whatever.

Smock[3] has demonstrated that this fertilizer breaks down under alkaline conditions to give dicyandiamide, a relatively insoluble compound, toxic to trees, which remains in the soil a long time. On acid soils the product of decomposition is urea, which in turn is converted into ammonia. The ammonia is then nitrified. Cyanamid has had a wide use in eastern orchards, apparently with satisfactory results. Under some California conditions its use seems dangerous, at least for some fruits with application of more than 2½ pounds per tree.

Another source of nitrogen recently introduced is liquid ammonia—that is, gaseous ammonia liquified under pressure and distributed in

steel tanks. It is applied by bubbling the gas from the cylinders into the irrigation water at a rate sufficient to give the desired amount per acre. It contains about 80 per cent N, the most concentrated form of N used as a fertilizer. The advantages claimed include those of easy application, uniform distribution, rapid availability and use, and increased efficiency. In examining these claims, we see that the first, easy application, will be valid where the irrigation system gives a uniform flow and where changes in handling the water are not made frequently. On many hill-side orchards or in mixed orchards where spot fertilization is desired, the reverse would be true. The material must, furthermore, be applied at the season of irrigation. The grower who desires to fertilize in the winter or early spring must choose another source or apply an unnecessary irrigation. The second advantage, uniform distribution, might be valid with level checks and with a large water head. It has not been true with small heads of water, especially with long runs, in the furrow system. According to 1936 data more ammonia is held in the upper end of the run than in the lower. An orchard sampled as soon after irrigation as possible showed, for example, an ammonia concentration of 135 p.p.m. in the top 6 inches in the furrows at the upper end of the row. In the middle of the run, 12 trees down, the concentration was 70 p.p.m. At the lower end, 14 trees farther, it was only 55 p.p.m. The ammonia did not move into the middles between the furrows, samples showing the same as the unfertilized checks. It was all held in the surface sample of 6 inches. Evidently if 55 p.p.m. is enough under these conditions, a great deal too much is being applied at the upper end. If, on the contrary, 135 p.p.m. is required, those at the lower end are not getting enough.

There are not normally, in cultivated orchards in the irrigated sections, many absorbing roots in the top 6 inches of soil. Obviously, therefore, ammonia that remains in the fixed state will not be available to the trees. In the field, usually, the ammonia is nitrified by the bacteria in the surface soil, and the nitrates are subsequently leached into the root zone.

This process was well brought out in a 1935 study on the fixation of ammonia from sulfate of ammonia. This was begun to try to determine the reason for the lag in response often encountered in the field. A series of laboratory studies was made with three soils—the first a Yolo silt loam from Davis, with a field capacity of about 23 per cent; the second a San Joaquin loam with a field capacity of about 14 per cent; the third a Fresno sand with a field capacity of about 10 per cent. These soils were selected rather than heavier ones because Davey[8] has shown that in heavier soils

[8] Unpublished data by A. E. Davey, 1934.

considerable amounts of ammonia are fixed in the surface 2 inches. Soil samples were packed in celluloid tubes supported by wire frames. Ammonium sulfate was added at a rate equivalent to 1,000 pounds per acre, and was leached with distilled water. The soil columns were then divided into 3-inch increments, and the ammonia was determined. Even in the sand there was no penetration below the second increment—that is, the total penetration was not over 6 inches. Even with a heavy application of ammonium sulfate there was complete fixation in the top 6 inches of soil.

It seemed possible that in the field the results might not exactly follow those in the laboratory, because of structural differences in the soil. Worm holes, channels left by decayed roots, and the like might permit mass flow of solution to greater depths than in a packed tube. A series of plots, therefore, was laid out on Yolo sandy loam that had not been cropped for several years, having been used as a fruit dry-yard. There were no trees near enough to affect the result by absorbing any materials through the roots. The plots were divided into two sets of five each. One set received sulfate of ammonia (1,000 pounds per acre). The other received nothing. All plots were irrigated, after the application of the fertilizer, at the rate of about 3 acre-inches per acre. The first plot of each set was then sampled in 4-inch increments to a depth of 2 feet, again at 2-day intervals the first week, and then at approximately weekly intervals for 5 weeks. The second plot received a second irrigation after a week and then was sampled as above. The third received its second irrigation in 2 weeks, the fourth in 3 weeks, and the fifth in 4 weeks after the initial treatment; and all were sampled the same way as the first two.

Judging from the results there was nearly complete fixation in the first increment, with no subsequent movement of ammonia as such. By the end of the second week, however, sufficient nitrification had occurred so that irrigation water carried nitrates in appreciable quantities to the full depth of sampling. This would be well into the root zone. According to these results the rate of availability of nitrogen, applied as ammonia or salts of ammonia such as ammonium sulfate, in cultivated orchards under similar conditions would depend on the two factors: the rate of nitrification and the subsequent rate of leaching. With favorable moisture, temperature, soil bacteria, and soil structure, some nitrate may be at the root surface within 2 weeks. Under other conditions the interval may be greatly prolonged.

The "efficiency" of a fertilizer—that is, the response to a given amount of nitrogen supplied—can be determined only after a period of years under a variety of conditions. Data are not available to give adequate information on this point for the various sources of N.

RESULTS OBTAINED FROM FERTILIZER TRIALS BY THE AGRICULTURAL EXTENSION SERVICE

Besides the data gathered by members of the Pomology Division, information has come from many farm advisors in various counties. A series of trials, for example, extending over a ten-year period and dealing with peaches, prunes, and grapes has been conducted by the Sutter County Farm Advisor, Mr. R. H. Klamt, who has made his results available. These, obtained from numerous plots in a number of orchards, are fairly consistent: "The use of nitrogenous fertilizers on peach trees has become a standard practice, profitable in a large majority of cases where applied judiciously." Prunes have shown smaller responses to nitrogen; potash and phosphate have not been profitable on these fruits. As to quality, not only Mr. Klamt but growers and cannery fieldmen have observed that the application of nitrogen tends to make the canning peach more firm and therefore better for shipping. His results with potash confirm those given in the preceding sections that this material does not increase the sugar content of prunes, or the yield.

Trials in other counties by the farm advisors have, in general, confirmed those just reported. In many cases the trees have not responded to any treatment. The response to nitrogen has often proved profitable, but very seldom have even doubtful responses to other elements been indicated.

DISCUSSION AND CONCLUSIONS

The experience recorded here with K and P as fertilizers for trees generally agrees with results found elsewhere. In few, if any, well-authenticated cases have trees responded profitably to phosphate. Often this fact may be attributed to fixation, the material never reaching the tree roots. In many instances the tree apparently obtains adequate supplies at a very low level of phosphate nutrition and will not respond to greater amounts. The fact that on soils poorly furnished with P, trees did not show P deficiency when the intake was reduced by the application of N indicates that small amounts of P are sufficient. Concentrations of less than 0.5 p.p.m. of phosphate ion have proved adequate[2] for normal functioning of trees when this concentration is maintained in the soil solution.

In a few recorded cases covercrops have failed to grow without phosphate applications. In these cases an indirect benefit to the trees has been secured by using this material even though the trees did not respond directly in the absence of covercrops.

Phosphate-deficiency symptoms have been described for various spe-

cies by a number of investigators. In all cases where these symptoms have been described for fruit trees, the trees were grown under artificial conditions, usually in sand culture with a nutrient solution in which P had been omitted. The common appearance of such trees is: bronzed leaves which are dark green under the bronzing; short internodes; and a small total amount of growth.

Potassium has benefited the trees in more cases than has phosphate. In at least three experiments with fruit trees in America, K has given response; and in Europe it is frequently beneficial. In California, however, the response to K has been usually similar to that recorded in these experiments, that is, negligible. In the two limited areas where Lilleland has secured definite response to K, the cost has been prohibitive.

Potassium deficiency shows itself in scorched leaves, the margins usually turning brown first, or in some cases in a mottling type of chlorosis. In extreme cases the twigs die back at the ends. When growth is resumed a lateral bud becomes the leader. This type of growth gives a compact head of more or less zigzag branches. In some cases death of the tree ensues. The symptoms are worse after years of heavy crops and appear about midsummer when hot weather occurs. In those cases where improvement in trees has resulted from the use of commercial quantities of potash, some deficiency symptoms were evident.

This situation leaves nitrogen as the only major fertilizer normally to be considered in the orchard program. The data presented above indicate a common but not universal response of trees to this element. Many sources of nitrogen are now available. They are commonly divided into two groups, organic and inorganic. The first includes such materials as fish meal, tankage, cottonseed meal, manure, and urea; the second chiefly ammonium sulfate, sodium nitrate, calcium nitrate, cyanamid, and liquid ammonia. For most California orchards the choice of materials depends primarily on price, with the exception of cyanamid. Because cyanamid may injure trees when used in large quantities or on alkaline soils, it should be applied only on neutral or acid soils and then only with precautions against damage.

To receive the maximum benefit per dollar of expense for fertilizer, the grower should buy his nitrogen on the basis of cost per unit of nitrogen distributed in the field. Suppose, for example, he is considering manure at $2.00 per ton delivered at the side of the orchard, ammonium sulfate at $35.00 per ton, and liquid ammonia at $180. Let us assume that the manure runs 1.5 per cent N, ammonium sulfate 20.5 per cent N, and liquid ammonia 80 per cent N. The cost per pound of actual nitrogen in these materials will then be 6.7 cents in manure, 8.5 cents in sulfate of am-

monia, and 11.2 cents in liquid ammonia. The cost of application varies greatly with the method; but the average per ton for manure is about $0.75, or 2.5 cents per pound of N. The cost of distributing ammonium sulfate averages about $1.50 per ton or nearly 0.4 cent per pound of N. The sales company handles the distribution of the liquid ammonia. The total cost per pound of nitrogen in these materials in the orchard becomes 6.7 plus 2.5 or 9.2 cents for manure, 8.5 plus 0.4 or 8.9 for sulfate of ammonia, and 11.2 cents for liquid ammonia. The relative cost of the nitrogen in the other materials can be determined in the same way.

The percentage of nitrogen in manure used in the example given above should not be taken as the content of every lot available. The amount may vary from as little as 0.5 per cent to more than 2 per cent, being influenced by the source—whether chicken, sheep, horse, or cow manure—storage conditions, leaching, the amount and character of litter. Large purchases should be made only on a guaranteed nitrogen basis.

There are many arguments upholding one of these materials above another. One very common has been the effect on the acidity of the soil. According to tests on many of the plots the effects of the various fertilizers used have been slight and commercially unimportant. In all cases tested, the effect has been confined to the surface foot of soil. Although there may be important effects upon soil acidity in some places, the point is apparently minor on most of our fruit soils, which are usually neutral or slightly alkaline. The change to an acid condition in consequence of using ammonium sulfate or other acid-forming fertilizers would be very slow and easily counteracted. The shift in the opposite direction by calcium nitrate, calcium cyanamid, sodium nitrate, and similar compounds would likewise be slow; and only prolonged use of such a fertilizer would normally cause too high a degree of alkalinity. Six yearly applications of sodium nitrate, for example, a total of 50 pounds per tree, with soil slightly on the acid side, failed to change the acidity appreciably. A similar amount of ammonium sulfate applied to a slightly alkaline soil caused a definite but unimportant shift toward neutrality, near the surface. Unless the soil is already dangerously acid or alkaline it is not liable to be made so by ordinary amounts of the common fertilizers.

Many advantages claimed for one material or another are related to the nonnitrogenous portion of the fertilizer—the sulfur, lime, phosphate, or other ingredient having many virtues ascribed to it. Judging from common experience the amounts generally used do not carry enough of these substances to benefit the trees greatly.

Time of availability may be important under some conditions. Fertilizers in which the nitrogen is present as ammonia require a period for

nitrification before the nitrogen is available to the trees. The ammonia is first fixed in the surface soil, then nitrified, then carried into the root zone as nitrate. A period must be allowed for these processes if the grower expects the nitrogen to be absorbed before a certain time. If, for example, the nitrogen is to be made available before blossoming in order to increase the set of fruit, the ammonia-carrying material should be applied early enough so that nitrification can occur and so that spring rains will carry nitrate to the root zone. Experience would indicate about a month as the minimum time allowance at that season. The nitrates are not fixed, but will penetrate as soon as rain or irrigation water is applied to take them down. Urea seems to fall in a different category. Although it is not fixed itself, the first change it undergoes is the formation of ammonia, which is fixed. If this change occurs in the surface soil the process then goes on as if ammonia had been added. If urea has been leached into the root zone first, apparently the ammonia may be used directly by the tree without going through the nitrate stage.

The processes through which cyanamid goes are more complex, the ordinary sequence being cyanamid to urea to ammonia to nitrate. As indicated before, this sequence may be disturbed by alkalinity or by some other factors with the production of dicyandiamide, which is highly toxic. Cyanamid injury may be confined to leaf tipburn or may extend to heavy defoliation or even to the death of many shoots. With very large applications entire trees may be killed. Under suitable conditions and properly handled, cyanamid is entirely satisfactory.

The effect of increasing one substance on the absorption of another has been mentioned—notably the mutual effect of nitrate and phosphate. In this case an excess of one ion causes a decreased absorption of the other. There is no assurance that all the substances in a fertilizer, even though soluble and not fixed by the soil, will be absorbed by the tree in the proportion in which they may be added. It is therefore futile to attempt a so-called "balanced ration" fertilizer for trees. Trees function well throughout a wide range of concentrations of most of the nutrient materials and over a wide range from acidity to alkalinity. Within those limits variations in concentration show surprisingly little effect on growth and fruiting.

Often neglected in consideration of the fertilization program is the volume of soil in which root development has taken place. This volume may vary tremendously with planting distance and with depth of effective rooting. For standard trees the limits are about 500 cubic feet for the minimum and 15,000 cubic feet for the maximum, the usual volume being approximately 2,000 cubic feet or about 150,000 pounds of soil. With

even a slow rate of supply and a low concentration, the total amount of any nutrient presented to the root surfaces for absorption is very large in such a soil mass. The fact that tree roots remain in the soil throughout the year and continue to function most of the time, giving a longer period in which to accumulate the needed nutrients than in most annuals, also helps explain the difference in response between trees and annual crops.

The fact that tree roots are somewhat active through most of the winter is one reason for the success of fall fertilization. Data on this practice in California are being gathered, but are not yet complete. Results elsewhere indicate it to be satisfactory under suitable conditions. Nitrogen applied in the fall tends to be absorbed by the roots and accumulated in the tree to be available for blossoming and growth in the spring. Though fall fertilization is attended with some danger of leaching below the depth of root acivity in very light soils or in areas of heavy winter rainfall, most fruit sections in California present no serious problem in this respect. This statement is especially true where ammonia has been used in some form and fixed, thereby checking the rate of penetration of the material.

As this discussion indicates, the behavior of annual crops is not a reliable guide to fertilizer practice for trees. In many recorded cases trees have failed to respond to a fertilization program that is essential for field crops on the same soil. Trees have, for example, made good growth and not responded to applications of phosphate on soils so low in phosphate that corn will not grow more than 2 feet high.

For similar reasons chemical tests of soil fertility do not always agree with tree performance. Nearly all the field-testing equipment has been designed for field crops and for surface soils. It is not adequate for trees. Even expensive and relatively difficult laboratory tests based on accurate field sampling are by no means satisfactory.

We have therefore, as a practical means of determining the fertilizer needs of an orchard, only the behavior of the trees and their response in test plots.

The lack of nitrogen shows itself in short growth of shoots; small and yellowish leaves, falling early in the autumn; often a heavy bloom accompanied by a heavy drop and light set of fruit; and failure of the fruit to size even when the crop is light. These symptoms, when other operations such as pruning and irrigation have been properly performed, usually indicate a serious lack of nitrogen. It should be clearly understood that fertilization is not a substitute for these practices, but a supplement to them.

No system of diagnosis available surpasses test plots as a means of

determining a fertilizer program. Even results obtained by neighbors are not a wholly reliable guide, since differences in soil, treatment, age, or variety may cause differing response. A plot selected as representative of the orchard and treated with a fertilizer for two or three years should give a good indication of the results to be expected over the whole orchard. Such a plot should be not less than 20 trees if a single plot is used and may be in any convenient form. A single row, two rows of 10, or a block 4 by 5 may be used. In all cases, an untreated plot should be left for comparison. Obviously one cannot compare yields of a block for successive years as a guide to fertilizer response. That is, if a block has given a certain yield one season and is then fertilized, the yield compared with the earlier one is not a valid basis for estimating the response to the fertilizer. Climatic factors and previous performance affect yields too greatly for such comparisons to be significant. The plot method of testing is a slow, but in the long run very satisfactory and economical, method of determining fertilizer needs.

Having found that nitrogen is necessary—if such be the case—one must next consider the amount to use. Here the custom of the district is a help, and the response of the trees the final criterion. Common practice is to apply about 25 pounds of actual nitrogen per acre to newly planted trees where it is necessary and to increase this amount to a maximum of 100 to 150 pounds of N for old trees. One hundred pounds of N is approximately 500 pounds of ammonium sulfate. These amounts vary widely according to local conditions.

Summarizing the results of tests over a ten-year period on peaches, prunes, pears, apricots, and almonds by the Division of Pomology and other tests by the Extension Division as well as of experiments elsewhere and of field observations leads to the following conclusions:

1. Deciduous fruit trees have not given profitable responses to potassium or phosphate in California in the cases studied.

2. Response to nitrogen, though common, is not always obtained.

3. The source of nitrogen seems to be of minor importance on the basis of present experience, except with materials that may be toxic under some conditions.

4. The unit price of nitrogen seems to be the major factor in the choice of nitrogenous fertilizers.

5. Individual plot tests on each orchard are the most satisfactory means now at our disposal of determining whether nitrogen is needed and what amount should be applied.

6. Fertilization is not a substitute for proper pruning, irrigation, or other important cultural practices.

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